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Optimisation of parking guidance and information systems display configurations

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Abstract

Operators of parking guidance and information (PGI) systems often have difficulty in determining the best car park availability information to present to drivers in periods of high demand. This paper describes a behavioural model of parking choice incorporating drivers perceptions of waiting times at car parks based on PGI signs. This model was used to predict the influence of PGI signs on the overall performance of the traffic system.

Relationships were developed for estimating the arrival rates at car parks based on trip patterns, driver characteristics, car park attributes as well as the car park availability information displayed on PGI signs. Drivers' perceptions of waiting times at car parks were assumed to be influenced by the PGI signs for observers of the signs and actual car park utilisation levels for non-observers. The model assumes that the choice of car park does not change after entering the city centre, even if conditions observed are different from those initially perceived.

A mathematical programme was formulated to determine the optimal display PGI sign configuration to minimise queue lengths and vehicle kilometres of travel (VKT). The model was limited to off-street parking choices and illegal parking was not incorporated. A simple genetic algorithm was used to identify solutions that significantly reduced queue lengths and VKT compared with existing practices.

These procedures were applied to an existing PGI system operating in Tama New Town near Tokyo. Significant reductions in queue lengths and VKT were predicted using the optimisation model. This would reduce traffic congestion and lead to various environmental benefits.

Keywords: Parking guidance and information systems; Behavioural modelling; Optimisation; Genetic algorithms

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1. Introduction

Intelligent transport systems (ITSs) allow a wide range of real-time information to be presented to drivers. They have the potential to reduce many of the problems associated with the use of the motor car within cities, including congestion, air pollution and accidents. Parking guidance and information (PGI) systems are amongst the most common type of ITS currently operating in European and Japanese cities.

PGI systems typically rely on variable message signs (VMSs) to present information on the direction to and availability of spaces at car parks. There are numerous goals for PGI systems, including reducing cars searching for available spaces as well as reducing queuing at popular car parks (Polak et al., 1990).

A common problem associated with PGI systems is determining the best availability status to display on the signs. This particularly relates to periods where demand levels are approaching capacity. Since signs are generally located some distance from car parks, PGI system operators must determine when to display FULL or QUEUES for car parks before their utilisation has reached capacity. Similar issues arise in systems that display the number of available spaces.

2. Systems analysis

The temporal utilisation of car parks is influenced by the arrival and departure rates of vehicles. Drivers' choice of a car park within an urban centre is influenced by a number of factors, including urban trip patterns, driver characteristics, attributes of car parks and PGI signs. The model presented here investigates how the performance of central city parking systems is influenced by the operation of PGI signs. Fig. 1 describes how queue lengths and VKT are estimated based on the predicted arrival rates at car parks.

3. Parking choice model

A generalised cost function is used to represent the various factors influencing parking choice, Eq. (1) (Thompson and Richardson, 1998). The access time, waiting time, fee and walking time are combined with importance weightings to estimate the disutility of car parks, as shown in Eqs. (2)–(5). Motorists are characterised by their entrance link and final destination zone within a city centre.

This model provides a simplistic representation of parking choice, which is based on a number of assumptions, including:

(i) all car parks are off-street (no on-street parking is allowed);
(ii) there is no illegal parking;
(iii) all drivers observing the PGI sign board believe the information to be accurate;
(iv) drivers make their parking choice at the location of the sign boards;
(v) once a car park is chosen, drivers do not change their choice, even if they observe different conditions at car parks than those perceived when the choice was made.

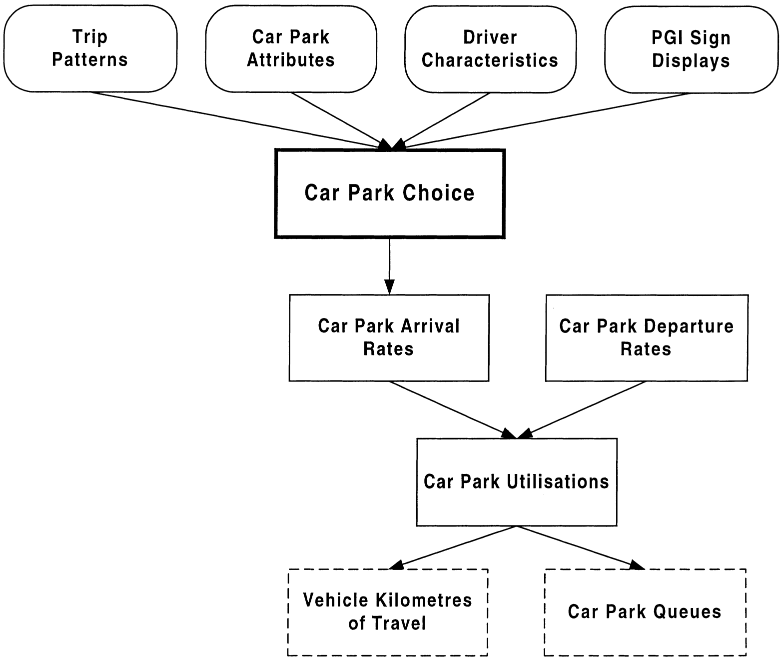

Fig. 1. City centre parking guidance and information systems analysis.

$$\mathrm{DU}_{ijk} = \mathrm{ADU}_{ij} + \mathrm{WDU}_j + \mathrm{DDU}_j + \mathrm{EDU}_{jk}, \tag{1}$$

$$\mathrm{ADU}_{ij} = \alpha_{\mathrm{t}} t_{ij}, \tag{2}$$

$$\mathrm{WDU}_j = \alpha_{\mathrm{wt}} \times wt_j, \tag{3}$$

$$\mathrm{DDU}_j = \frac{\alpha_{\mathrm{fee}} \times \mathrm{fee}_j}{\mathrm{VOT}}, \tag{4}$$

$$\mathrm{EDU}_{jk} = \alpha_{\mathrm{ttw}} \times \mathrm{ttw}_{jk}, \tag{5}$$

where

DU_{ijk}	Dis-Utility for motorists travelling from entrance link i, selecting car park j, with final destination in zone k
ADU_{ij}	Access Dis-Utility for motorists travelling from entrance link i, selecting car park j
WDU_j	Waiting Dis-Utility for motorists selecting car park j
DDU_j	Direct Dis-Utility for motorists selecting car park j
EDU_{jk}	Egress Dis-Utility for motorists selecting car park j with final destination in zone k
VOT	Value of Time ($/min)
t_{ij}	in-vehicle travel time from entrance link i to car park j (min)
wt_j	waiting time at car park j (min)
fee_j	fee at car park j ($)

ttw_{jk}	walking time from car park j to final destination k
α_{ttv}	relative importance weighting coefficient of in-vehicle travel time (ttv)
α_{wt}	relative importance weighting coefficient of waiting time at car park (wt)
α_{fee}	relative importance weighting coefficient of car park fee (fee)
α_{ttw}	relative importance weighting coefficient of walking time (ttw)

The probability that motorists choose a particular car park is influenced by the relative disutilities of car parks, Eqs. (6) and (7). Travel times are based on the traffic and pedestrian networks within a city centre. A constant perceived waiting time is assumed at car parks for drivers observing the PGI signs displaying car parks to be unavailable. Drivers not observing the PGI signs are also assumed to perceive a constant waiting time at car parks having a high utilisation (e.g. above 95%). These drivers are also assumed to have accurate information regarding the actual utilisation of car parks.

$$P^{\mathrm{o}}_{ijk} = \frac{\mathrm{e}^{-\alpha \mathrm{DU}_{ijk}}}{\sum_{j=1}^{J} \mathrm{e}^{-\alpha \mathrm{DU}_{ijk}}} \quad (i = 1, \ldots, I;\ j = 1, \ldots, J;\ k = 1, \ldots, K), \tag{6}$$

where P^{o}_{ijk} is the probability of selecting car park j from link i with destination zone k having observed the PGI sign board, α the scale parameter, I the number of entrance links, J the number of car parks and K is the number of destination zones. Here,

$$wt_j = \begin{cases} C & \text{if PGI sign board displays car park } j \text{ not available in } [S_t, S_{t+1}], \\ 0 & \text{otherwise,} \end{cases}$$

S_l is the start of time interval l and S_{l+1} is the start of time interval $l + 1$, where C is the perceived waiting time at car park (min)

$$P^{\mathrm{no}}_{ijk} = \frac{\mathrm{e}^{-\alpha \mathrm{DU}_{ijk}}}{\sum_{j=1}^{J} \mathrm{e}^{-\alpha \mathrm{DU}_{ijk}}} \quad (i = 1, \ldots, I;\ j = 1, \ldots, J;\ k = 1, \ldots, K) \tag{7}$$

P^{no}_{ijk} is the probability of selecting car park j from link i with destination zone k having not observed the PGI sign board. Here,

$$wt_j = \begin{cases} C & \text{if } U_j > T \text{ at time } D_l, \\ 0 & \text{otherwise,} \end{cases}$$

where U_j is the utilisation of car park j at time D_l (%), T the non-observers utilisation threshold (%) and D_l is the time that the PGI display configuration for interval l is determined.

4. Estimation of vehicle arrivals

The model developed here assumes that the availability status of car parks displayed on the PGI signs is constant for small time intervals (e.g. 5 or 10 min). The arrival of vehicles at car parks must be predicted for three separate intervals, Fig. 2, Table 1, Eqs. (8) and (9).

During the first interval this rate is assumed to be constant and equal to the existing rate experienced when the display configuration was determined. Drivers arriving at car parks during

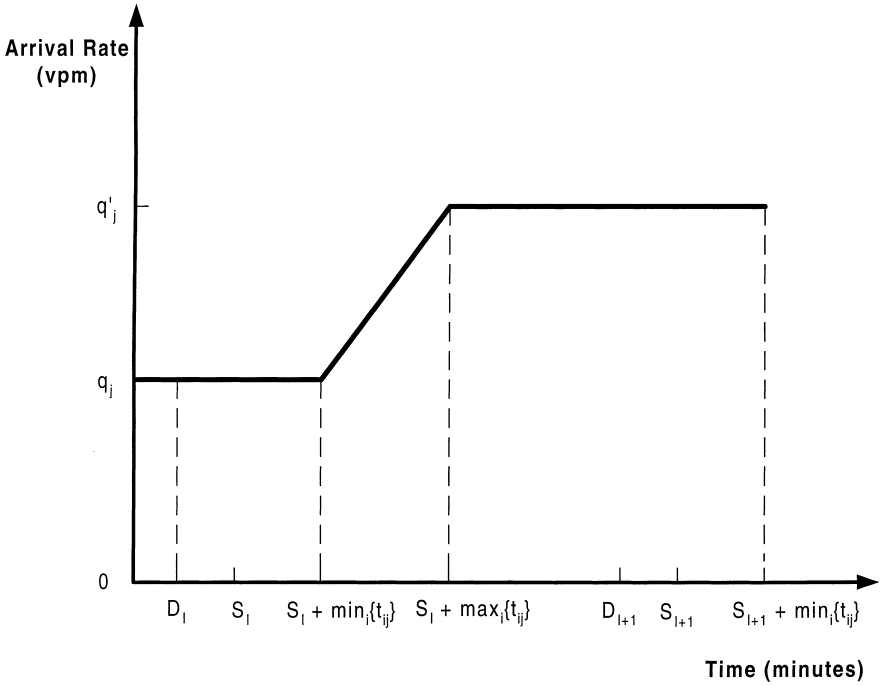

Fig. 2. Car park arrival rate periods.

Table 1
Arrivals by time intervals at car parks[a]

PGI display interval	Time interval	Number of arrivals
Current	$[D_l, S_t + \min_i\{t_{ij}\}]$	$q_j(S_l + \min_i\{t_{ij}\} - D_l)$
Current and next	$[S_l + \min_i\{t_{ij}\}, S_l + \max_i\{t_{ij}\}]$	$(\max_i\{t_{ij}\} - \min_i\{t_{ij}\})(q_j + (q'_j - q_j)/2)$
Next	$[S_l + \max_i\{t_{ij}\}, S_{l+1} + \min_i\{t_{ij}\}]$	$q'_j(S_{l+1} - S_l + \min_i\{t_{ij}\} - \max_i\{t_{ij}\})$

[a] where A_j is the expected arrivals at car park j during $[D_l, S_{l+1} + \min_i\{t_{ij}\}]$ (veh), q_j the arrival rate at car park j before D_l (veh/min), t_{ij} the travel time between sign board i and car park j (min) and q'_j is the arrival rate at car park j for all vehicles passing sign boards during interval $[D_l, S_{l+1} + \min_i\{t_{ij}\}]$ (veh/min).

this time interval can have only been influenced by the current configuration being displayed on the signs. This rate is assumed to continue until vehicles begin arriving at car parks after observing the new configuration has been determined. This involves determining the minimum travel time from signs to car parks.

The arrival rate for the second period is influenced by both the current display configuration as well as the one to be determined. This is due to the different travel times from the signs to car parks in the network.

For the third time interval, the influence of the PGI signs on parking is limited to only the display configuration to be determined. This period commences after all drivers arriving at the car park would have had the opportunity of observing the new configuration. This period finishes when it is possible for vehicles to arrive at a car park after observing the next display configuration after the one to be determined. Now, it can be shown that,

$$A_j = q_j\left(S_l - D_l + \frac{1}{2}\left(\max_i\{t_{ij}\} + \min_i\{t_{ij}\}\right)\right) + q'_j\left(S_{l+1} - S_l + \frac{1}{2}\left(\min_i\{t_{ij}\} - \max_i\{t_{ij}\}\right)\right), \tag{8}$$

$$q'_j = \sum_{i=1}^{I}\sum_{k=1}^{K} P(\mathrm{o})N_{ik}P^{\mathrm{o}}_{ijk} + \sum_{i=1}^{I}\sum_{k=1}^{K} P(\mathrm{no})N_{ik}P^{\mathrm{no}}_{ijk}, \tag{9}$$

where N_{ik} is the number of vehicles on link i with destination in zone k during $[S_l, S_{l+1}]$, $P(\mathrm{o})$ the probability observed PGI sign board and $P(\mathrm{no})$ is the probability did not observe PGI sign board $= 1 - P(\mathrm{o})$.

5. Configuration strategies

5.1. Optimisation model

A mathematical program based on the above relationships has been formulated to determine the optimal display configuration on the PGI signs.

The decision variables represent whether or not the PGI signs display car parks to be available. For each display interval, the status shown for each car park on the PGI signs can be represented as a boolean variable

$$x_{ij} = \begin{cases} 1 & \text{if sign } i \text{ displays car park } j \text{ to be available,} \\ 0 & \text{otherwise.} \end{cases}$$

The objective function can be formulated for a specific goal, for example, minimum queue lengths at car parks (Eq. (10)) or VKT (Eq. (11)). Expressions for alternative goals such as minimising waiting times could also be developed.

$$\text{Min. } Z = \sum_{j=1}^{J} \max\{A_j - E_j, 0\}, \tag{10}$$

where E_j is the number of vehicles exiting car park j during $[D_l, S_{l+1} + \min\{t_{ij}\}]$

$= r_j(S_{l+1} + \min\{t_{ij}\} - D_l)$ (veh.)

where r_j is the departure rate at car park j immediately before D_l (veh/min)

$$\text{Min. } Z = \sum_{i=1}^{I}\sum_{k=1}^{K} d_{ij}P(\mathrm{o})N_{ik}P^{\mathrm{o}}_{ijk} + \sum_{i=1}^{I}\sum_{k=1}^{K} d_{ij}P(\mathrm{no})N_{ik}P^{\mathrm{no}}_{ijk}, \tag{11}$$

where d_{ij} is the travel distance from sign board i to car park j (km)

If each sign board displays the availability status of all car parks in the system, there are 2^{JK} possible display status combinations for each display interval. Since there is a very large number of possible display configurations for this type of model and the complex relationships, an exact solution procedure could not be used. However, a simple genetic algorithm (GA) was developed to identify good solutions within a reasonable computational time.

Genetic algorithms are heuristic techniques that have already been used in a number of traffic signal timing applications (Foy et al., 1992; Hadi and Wallace, 1993; Sano et al., 1995; Clement and Anderson, 1997; Sung et al., 1997).

Here, a complete configuration of car park availability status displayed on all the signs during a specified time interval was coded as a vector (chromosome):

$$\delta_m = \begin{cases} 1 & \text{depicting car park } (l/J - [l/J]) \times J \text{ available on sign } [l/J] + 1, \quad (m = 1, \ldots, KJ), \\ 0 & \text{depicting car park } (l/J - [l/J]) \times J \text{ unavailable on sign } [l/J] + 1, \quad (m = 1, \ldots, KJ), \end{cases}$$

where $[1/J]$ is the integer less than or equal to $1/J$.

The GA maintains a set (population) of vectors (chromosomes) – potential parents, from which a next generation is produced using a number of operators. Offspring replace the parent(s) to create a next generation. Procedures based on a simple genetic algorithm were implemented (Goldberg, 1989).

5.2. Utilisation thresholds

The availability status of car parks for existing PGI systems are typically determined using utilisation thresholds where once a predetermined threshold at a car park is reached (e.g. 95%) all the signs display that car park to be "FULL" or "QUEUES" to indicate that it is unavailable. This type of timing strategy will be used to compare the performance of the optimisation model.

6. Internal verification

6.1. Test network and parameters

A small network representing a hypothetical city centre was constructed to check the internal consistency of the model. The location of the traffic links, PGI signs, off-street car parks, zone boundaries and centroids are shown in Fig. 3.

Parameter values (Table 2) were adopted from previous studies of drivers' responses to PGI systems (Asakura and Kashiwadani, 1994; Polak and Axhausen, 1994; Thompson and Bonsall, 1997) and information usage (Smith and Phillips, 1992; Thompson et al., 1999). A high relative weighting coefficient for walking was used to reduce the likelihood of travellers choosing a car park a long distance from their final destination. Drivers were assumed to be travelling to destination zones, from entrance links where the PGI signs are located (Table 3). All drivers were assumed to have a parking duration of 1 h. All car parks have the same fee ($2/h), capacity (500 spaces) but car park P_1 has initially higher arrival and departure rates (Table 4). Car parks P_2, P_3 and P_4 have 80% utilisation at the time at which the next display configuration is decided.

6.2. Queue lengths

Queue lengths were predicted based on the general practice, where once a pre-determined threshold utilisation level is reached all PGI signs display that car park to be "FULL".

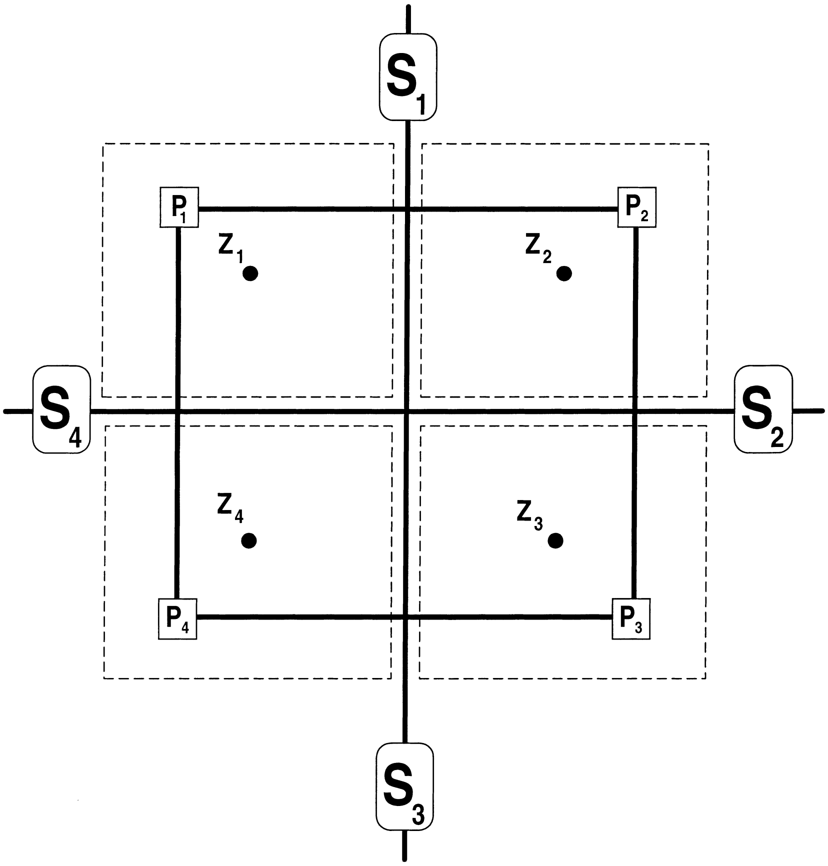

Fig. 3. Test network.

Table 2
Model parameters

Probability observe sign board (P^o)	0.7
Decision time (D_l)	5.0 (min)
PGI display time (S_l)	7.0 (min)
Sign board time lag ($S_l - D_l$)	2.0 (min)
Expected waiting time (if queue) (C)	5.0 (min)
Non-PGI observers utilisation threshold (T)	95.0 (%)
Sign board time interval ($S_{l+1} - S_l$) (length of display interval)	10.0 (min)

Table 5 presents the predicted total queue lengths at all car parks when the availability status displayed for car park P_1 is determined using a utilisation threshold. Here, all PGI signs display car park P_1 to be available only if its utilisation is below the threshold utilisation level. All signs display that car parks P_2, P_3 and P_4 have AVAILABLE spaces.

Cells in the upper triangular segment of Table 5 correspond to the situation, where the PGI signs display car park P_1 to be unavailable since these cases are where the utilisation is greater

Table 3
Test network origin and destinations (veh/h)

Entrance link and sign board no.	Destination zone			
	Z_1	Z_2	Z_3	Z_4
S_1	350	175	175	175
S_2	350	175	175	175
S_3	350	175	175	175
S_4	350	175	175	175

Table 4
Test network car park attributes

	Car park			
	P_1	P_2	P_3	P_4
Initial arrival rate (veh/min)	20.0	15.0	15.0	15.0
Initial departure rate (veh/min)	15.0	10.0	10.0	10.0

Table 5
Predicted systemwide queue lengths by P_1 initial utilisations and PGI trigger threshold levels

		Initial utilisation of car park P_1 (%)										
		90	91	92	93	94	95	96	97	98	99	100
PGI Utilisation Threshold (%)	90	24.8	24.8	24.8	24.8	24.8	90.5	90.5	90.5	90.5	90.5	90.5
	91	48.1	24.8	24.8	24.8	24.8	90.5	90.5	90.5	90.5	90.5	90.5
	92	48.1	53.1	24.8	24.8	24.8	90.5	90.5	90.5	90.5	90.5	90.5
	93	48.1	53.1	58.1	24.8	24.8	90.5	90.5	90.5	90.5	90.5	90.5
	94	48.1	53.1	58.1	63.1	24.8	90.5	90.5	90.5	90.5	90.5	90.5
	95	48.1	53.1	58.1	63.1	68.1	90.5	90.5	90.5	90.5	90.5	90.5
	96	48.1	53.1	58.1	63.1	68.1	7.4	90.5	90.5	90.5	90.5	90.5
	97	48.1	53.1	58.1	63.1	68.1	7.4	12.4	90.5	90.5	90.5	90.5
	98	48.1	53.1	58.1	63.1	68.1	7.4	12.4	17.4	90.5	90.5	90.5
	99	48.1	53.1	58.1	63.1	68.1	7.4	12.4	17.4	22.4	90.5	90.5
	100	48.1	53.1	58.1	63.1	68.1	7.4	12.4	17.4	22.4	27.4	90.5

than the utilisation threshold. High utilisation levels (to the right of the dashed line) represent the situation, where drivers not observing the PGI signs perceive car park P_1 not to be available.

It can be seen that the largest queues occur when the utilisation levels at car park P_1 are above 95% and the utilisations at car park P_1 are above the threshold (i.e. when the PGI signs show that car park P_1 is not available). In this case, motorists not observing the PGI signs also perceive car park P_1 not to be available. This results in considerable queues being predicted at both car parks P_2 and P_4. Here, the PGI signs have deflected a considerable number of drivers away from car park P_1 resulting in a substantial number of vacancies at car park P_1.

Significant queues are also predicted when the utilisation levels at car park P_1 are below 95% and below the threshold (PGI signs indicating that it is available). In these situations the queued vehicles are predicted at only car park P_1. Moderate queues are predicted at both car parks P_1 and P_2 when utilisation levels are below 95% and below the threshold level. Generally the smallest queues are predicted when the utilisation at car park P_1 is above 95% and below the utilisation threshold. In these cases, queues are predicted only at car park P_1. This is largely due to the assumption that non-observers are fully informed as to the utilisation of car parks. These results show that use of a simple rule to trigger PGI signs to show FULL can lead to an increase in queuing in the system.

6.3. Vehicle kilometres of travel

The optimisation model described above can be used to determine the display configuration to minimise queue lengths or VKT. Here, a binary vector representation of the display configuration is used within the GA. Note, there is no constraint within this model requiring the availability status for car parks to be identical on all signs.

For all utilisation levels between 90% and 100% for car park P_1 the optimisation model was able to identify a display configuration producing no queues at any of the car parks (Table 6). This configuration is able to spread the demand amongst the unused capacity by shifting a substantial proportion of demand away from car park P_1 while balancing the existing supply and temporal demand at the other car parks.

Table 7 shows that VKT levels are highest when the utilisation levels at car park P_1 are less than 95% and below the PGI utilisation threshold. Here, the PGI signs display car park P_1 to be available and a driver not observing the PGI sign also perceives car park P_1 to be available. Most drivers entering the city past PGI signs S_2 and S_3 travelling to destination zone Z_1 choose car park P_1.

The lowest VKT levels are when there are high utilisation levels and they are above the threshold. Here, the PGI signs display car park P_1 not be available and non-observers also perceive car park P_1 as not available. In this case, a number of drivers travelling to zone Z_1 do not choose car park P_1 resulting in less distance travelled particularly from drivers entering the city centre from entrance links with signs S_2 and S_3. Motorists were discouraged from selecting car park P_1 (from the PGI signs and assumed perceptions) and typically selected a car park nearer to their entrance link.

The optimisation model was able to identify display configurations with substantially reduced VKT (Table 8).

Table 6
Optimal display configuration for minimum queue size[a]

Sign board	S_1				S_2				S_3				S_4			
Car park	P_1	P_2	P_3	P_4	P_1	P_2	P_3	P_4	P_1	P_2	P_3	P_4	P_1	P_2	P_3	P_4
Display status	S	S	F	S	F	F	F	F	F	F	S	S	F	S	F	F

[a] S – SPACES; F– FULL.

Table 7
Predicted systemwide VKT by P_1 initial utilisations and PGI trigger threshold levels

		Initial utilisation of car park P_1 (%)										
		90	91	92	93	94	95	96	97	98	99	100
	90	278	278	278	278	278	273	273	273	273	273	273
	91	292	278	278	278	278	273	273	273	273	273	273
	92	292	292	278	278	278	273	273	273	273	273	273
PGI	93	292	292	292	278	278	273	273	273	273	273	273
Utilisation	94	292	292	292	292	278	273	273	273	273	273	273
Threshold	95	292	292	292	292	292	273	273	273	273	273	273
(%)	96	292	292	292	292	292	286	273	273	273	273	273
	97	292	292	292	292	292	286	286	273	273	273	273
	98	292	292	292	292	292	286	286	286	273	273	273
	99	292	292	292	292	292	286	286	286	286	273	273
	100	292	292	292	292	292	286	286	286	286	286	273

Table 8
Lowest VKT solutions

Sign board	S_1				S_2				S_3				S_4				VKT
Car park	P_1	P_2	P_3	P_4	P_1	P_2	P_3	P_4	P_1	P_2	P_3	P_4	P_1	P_2	P_3	P_4	
Util. < 95%	S	F	F	F	F	S	S	F	F	F	F	S	S	F	F	S	232.1
Util. ⩾95%	S	F	F	F	F	S	S	F	F	F	S	S	S	F	F	S	225.6

7. Model application

7.1. The study network and data sets

The model was used to investigate the operational performance of the PGI system for Tama New Town, a regional centre approximately 50 km west of Tokyo. The existing PGI system provides availability information for off-street 11 car parks (Fig. 4). On-street parking is not permitted within the city centre.

Traffic count data from a peak period as well as land use pattern information were used to estimate an origin and destination matrix. High volumes were observed entering the city centre from links with PGI signs S_4 and S_7. Due to the spatial distribution of retail stores a high proportion traffic was estimated to have its final destination in zone Z_9, with moderate level of demand for zones Z_4, Z_5, Z_6 and Z_7. Parking survey data were used to estimate car park arrival and departure rates (Table 9). All car parks except P_2 had approximately 70% utilisation at the time at which the configuration of signs for the next display interval was determined. All car parks in Tama New Town are off-street with the same fee structure for short-term parking. Estimates of in-vehicle travel times and walking times were based on the location of the car parks, traffic and pedestrian links within the city centre (Fig. 4). Each choice parker was assumed to have the same parking duration of 1 h.

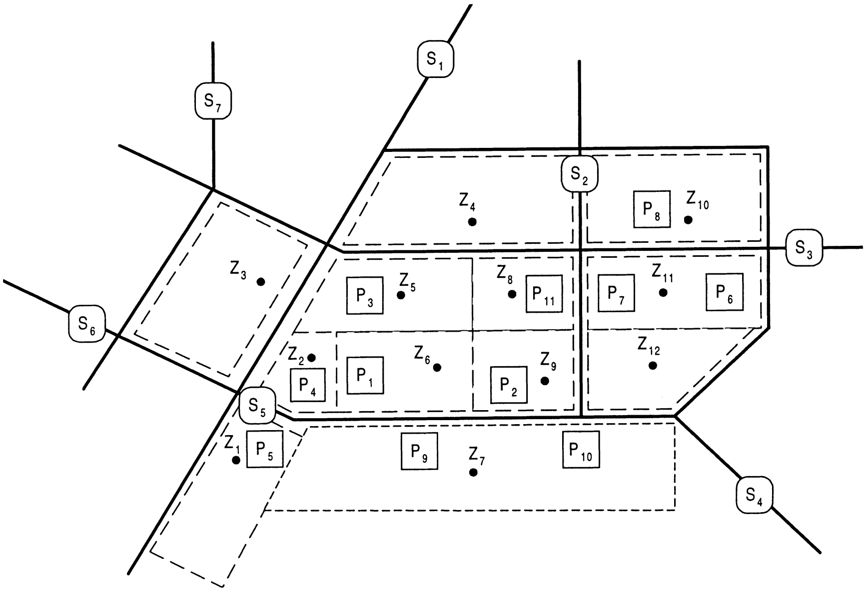

Fig. 4. Tama New Town network.

Table 9
Tama New Town car park attributes

	Car park										
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}
Capacity (veh)	800	130	330	140	130	800	120	220	100	100	90
Initial arrival rate (veh/min)	6.0	3.0	4.0	2.0	2.0	6.0	2.0	5.0	4.0	2.0	1.5
Initial departure rate (veh/min)	4.0	2.0	2.0	1.0	1.0	5.0	1.5	2.0	2.0	1.0	1.2

7.2. Queue lengths

Table 10 presents the predicted total queue lengths at all car parks when the availability status displayed for car park P_2 is determined using utilisation thresholds. Cells in the upper triangular segment correspond to the situation where the PGI signs display car park P_2 to be unavailable since this is when the utilisation is greater than the utilisation threshold. High utilisation levels (to the right of the dashed line) represent the situation where drivers not observing the PGI signs are assumed to perceive car park P_2 to be unavailable.

The largest queues occur when the utilisation levels at car park P_2 are below 95% and below the utilisation threshold (i.e. the PGI sign show that car park P_2 is available). In this case, motorists not observing the PGI sign also perceive car park P_2 to be available. This results in considerable queues being predicted at car park P_2. Here, the PGI signs have not been used to deflect drivers away from car park P_2 resulting in substantial queues there.

Table 10
Predicted systemwide queue lengths in Tama New Town by P_2 initial utilisations and PGI trigger threshold levels

		Initial utilisation of car park P_2 (%)										
		90	91	92	93	94	95	96	97	98	99	100
PGI Threshold Utilisation (%)	90	22.7	22.7	22.7	22.7	22.7	33.1	33.1	33.1	33.1	33.1	33.1
	91	39.1	22.7	22.7	22.7	22.7	33.1	33.1	33.1	33.1	33.1	33.1
	92	39.1	40.1	22.7	22.7	22.7	33.1	33.1	33.1	33.1	33.1	33.1
	93	39.1	40.1	41.1	22.7	22.7	33.1	33.1	33.1	33.1	33.1	33.1
	94	39.1	40.1	41.1	43.1	22.7	33.1	33.1	33.1	33.1	33.1	33.1
	95	39.1	40.1	41.1	43.1	44.1	33.1	33.1	33.1	33.1	33.1	33.1
	96	39.1	40.1	41.1	43.1	44.1	35.2	33.1	33.1	33.1	33.1	33.1
	97	39.1	40.1	41.1	43.1	44.1	35.2	36.2	33.1	33.1	33.1	33.1
	98	39.1	40.1	41.1	43.1	44.1	35.2	36.2	37.2	33.1	33.1	33.1
	99	39.1	40.1	41.1	43.1	44.1	35.2	36.2	37.2	38.2	33.1	33.1
	100	39.1	40.1	41.1	43.1	44.1	35.2	36.2	37.2	38.2	39.2	33.1

Large queues were also predicted when the utilisation levels at car park P_2 are above 95% and below the PGI threshold (i.e. PGI signs indicating that it is available). In this case, queues were predicted at both car parks P_2 and P_{11}. Car park P_{11} had small queues since motorists not observing the PGI signs are assumed to perceive car park P_2 to be unavailable. Moderate queues were predicted at car park P_{11} when utilisation levels are above 95% at car park P_2 and above the PGI threshold level. The smallest queues were predicted when the utilisation at car park P_2 is below 95% and above the PGI threshold. For these cases, queues were predicted only at car park P_{11}. These results illustrate that reduced queuing does occur by implementing the PGI utilisation threshold but this led to queues at another car park.

For all utilisation levels between 90% and 100% at car park P_2 the optimisation model was able to identify a PGI display configuration that predicted no queues at any of the car parks (Table 11). This configuration is able to spread the demand amongst the unused capacity by shifting a substantial proportion of demand away from car park P_2 while balancing the existing supply and temporal demand at other car parks. Here, a large proportion of signs display car parks P_2, P_6 and P_{10} to be unavailable.

Table 11
Optimal Tama New Town display configuration for no queues (car park P_2 95% utilisation)

		Car park										
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}
PGI sign	S_1	S	S	S	F	F	S	F	F	S	F	S
	S_2	S	F	F	S	S	S	S	F	F	F	F
	S_3	S	S	S	S	F	F	S	F	S	F	S
	S_4	F	F	S	F	F	F	S	S	F	S	F
	S_5	S	F	S	F	S	F	F	S	F	F	S
	S_6	S	F	F	S	F	F	F	F	S	F	F
	S_7	F	F	F	S	S	F	S	S	F	F	F

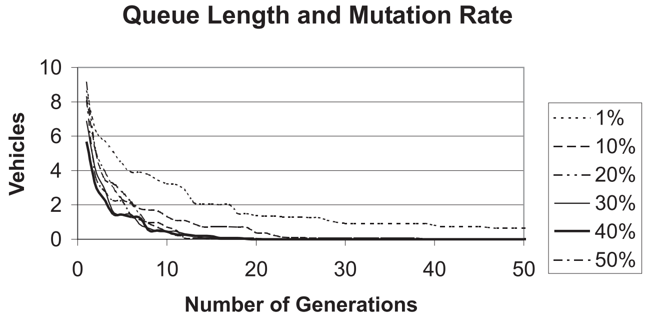

Fig. 5. Effect of mutation rate on queue lengths (crossover probability of 0.8).

Genetic algorithms have a number of parameters that can effect their performance, including the crossover rate, mutation rate and population size. The performance of the GA was investigated for a range of parameters.

With a population size of 20, the probability of crossover generally had little effect, but better results were obtained using moderately high mutation rates. The best results after each generation were averaged for 20 runs. Except for low mutation rates (less than 20%) the GA solutions quickly converged to zero queues with a crossover probability of 0.8 (Fig. 5).

7.3. Vehicle kilometres of travel

The optimisation model was also able to identify PGI display configurations that substantially reduced VKT. When using the utilisation threshold criteria with the utilisation at car park P_2 at 95%, the VKT was estimated to be 198 and 199 km where the utilisation threshold was below and above this level, respectively. However, the display configuration having lowest value of VKT identified by the optimisation model using the GA was 171 km, a reduction of approximately 14% (Table 12). Here, many inner car parks were displayed as being unavailable.

With a population size of 20, a high probability of crossover (0.8) and moderate mutation rate (20%) achieved the best performance for VKT (Fig. 6). Low levels of mutation often lead to premature convergence while high levels approached a random search.

Table 12
Optimal display configuration for VKT in Tama New Town

		Car park										
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}
PGI sign	S_1	S	F	S	F	F	F	F	F	F	F	S
	S_2	F	S	S	F	F	F	S	S	F	F	S
	S_3	F	F	F	F	S	S	F	F	S	S	S
	S_4	F	F	F	F	F	F	F	S	F	S	F
	S_5	S	S	S	S	F	F	F	S	F	S	S
	S_6	S	F	F	S	F	F	S	F	S	F	F
	S_7	F	F	S	S	F	F	F	F	F	F	F

With a crossover probability of 0.8 and mutation rate of 20%, increasing the population size tended to marginally improve performance. Fig. 7 presents the best results achieved after each generation were averaged for 20 runs. However, the computation time became significant when the population size was increased above 20 when implemented on a 266 MHz microprocessor (Table 13). A population size of 20 would allow the model to operate in real time.

The application of the model was limited to only one display time interval. However, it could be easy to implement to optimise the display configurations for multiple consecutive time intervals.

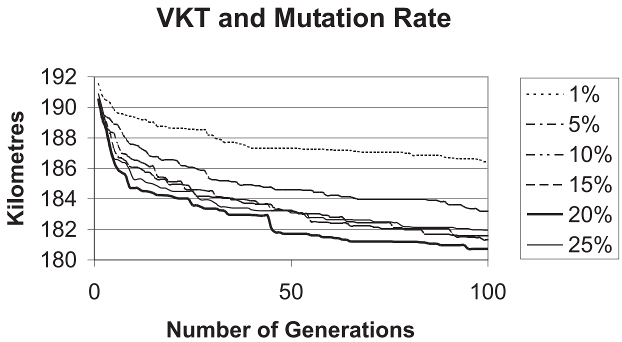

Fig. 6. Effect of mutation rate on VKT (crossover probability of 0.8).

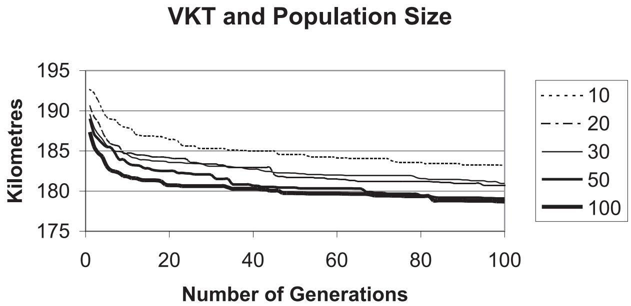

Fig. 7. Population size and VKT (crossover probability of 0.8, mutation rate 20%).

Table 13
Population size and processing time (266 MHz microprocessor)

Population size	Processing time (s)
20	49
30	73
50	122
100	245

8. Conclusions

This paper presented procedures that were developed for investigating the effects of PGI signs on parking choice behaviour. An optimisation model was able to determine PGI display configurations that had better performance than the existing method based on utilisation thresholds.

For minimising queue lengths, the optimisation model was able to spread excess demand between a number of facilities having adequate supply of parking. The total distance travelled was able to be reduced by directing motorists away from central car parks towards other available car parks near their entrance links.

Several of the simplifying assumptions used in the model may tend to overestimate the effect of the PGI signs would have on parking choice. In particular, if observers were not assumed to believe the availability of information, the potential of PGI systems to influence and manage traffic movements as well as parking choices would be reduced. A similar reduced effect would occur if illegal parking was incorporated as this would tend to be more prevalent in periods of peak demand. Permitting on-street parking would also tend to reduce the effect of the PGI signs on overall system performance.

As well, if drivers choice of car parks was permitted to change upon observing actual conditions at car parks, queues lengths may well be reduced at popular car parks. However, this effect would be less if non-observers were not assumed to have accurate information concerning the utilisation of car parks.

GAs provided an effective solution procedure for identifying optimal PGI sign configurations. The combination of behavioural choice and optimisation modelling offers potential for PGI operators to reduce traffic congestion in central city areas.

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